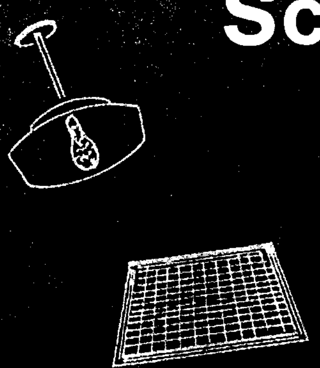
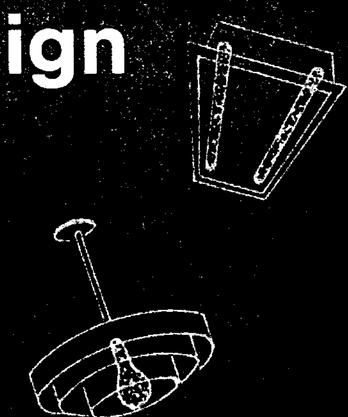
California School Lighting Design and Evaluation





A Procedure for the Prediction, Specification, and Evaluation of Visual Comfort and Visual Performance in Classrooms

CALIFORNIA STATE DEPARTMENT OF EDUCATION
Wilson Riles Superintendent of Public Instruction
Sacramento 1978

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Foreword

The design of school facilities should reflect the demands made upon such facilities by those who use them the most: the children and their teachers. However, a melding of the educational program and adequate facilities to house the program does not happen by accident; it must be planned. This document was prepared to help those involved in planning good lighting facilities for our public schools.

The school facility in which students and teachers are involved in the learning process should be attractive and comfortable, and it should be designed for the most economical use of indoor and outdoor space. One of the most crucial design elements of a school facility is the lighting. The utilization of solar and electrical sources of light should be controlled and directed to visual tasks of learners so that human energies will be utilized most efficiently in the learning process. No longer can we afford to waste precious sources of electrical energy on lighting systems that make seeing difficult. Students and teachers need balanced sources of light so that the eye can comfortably and efficiently see the visual tasks required in our varied educational programs.

This guide is intended to help school administrators, members of school district governing boards, architects, and engineers objectively evaluate school lighting systems. It is particularly important in these times to make the best possible use of energy sources while at the same time providing a visual environment of the highest quality possible.

Wilson Riles

Superintendent of Public Instruction

Preface

The California school lighting design and evaluation procedure described in this publication has proved to be a splendid facilities planning tool because it provides a step-by-step design method that, when used properly, results in balanced lighting for school facilities. The procedure also provides for a separate assessment and rating for visual performance and visual comfort, making possible calculated options between these two basic lighting design factors.

This document is particularly timely because it points out ways to provide good lighting installations with less consumption of electrical energy. The current national concern for the conservation of energy makes it imperative that every effort possible be made to conserve power resources and to make the energy consumed pay the highest practical dividends in positive results. The California school lighting design and evaluation procedure makes a significant contribution toward this goal.

Basically, this document is a designing tool for engineers with specific responsibility for illumination. Architects, school officials, personnel from reviewing-approving agencies, and other laypersons in the field of illuminating engineering are not expected to be able to work through the various steps. Their part in this lighting design and evaluation procedure is to understand the options worked out by the engineer and to participate in the judgment and priority-setting functions presented by the engineer. The architect and other responsible agents signify their understanding and approval of the agreed upon solution by signing the two-page "Basic Data and Grading Form for Proposed Lighting System."

This document is the direct result of the cooperative efforts of the Bureau of School Facilities Planning and persons from the private sector of illuminating engineering. Charles D. Gibson, former chief of the Bureau of School Facilities Planning, conceived and organized the publication. Bill F. Jones and Foster K. Sampson, both professional engineers, prepared the original document, which was published in 1973; and Mr. Jones assumed the responsibility for updating the contents for this 1977 edition.

The contents of this document have been presented to and reviewed by national technical organizations and committees and many individual consulting engineers concerned with the improvement of the visual environment in educational facilities.

We are grateful to all of those who helped with this publication.

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Deputy Superintendent for Administration

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Introduction

The design and evaluation procedure outlined in this publication is based on the fundamental principles that were expressed in previous recommendations and that were based on the best current knowledge of the many related aspects of the visual environment. From time to time the emphasis has changed from footcandle levels to luminance ratios and combinations of the two. In each instance, however, the purpose was to provide design and evaluation procedures for comfortable and adequate seeing conditions. The differences in these previous "practices" were in the degree of emphasis placed on the many factors that together make up the environment. The basic characteristics that provide for visual comfort and adequacy are the same regardless of the environment or the task to be accomplished. It is still true that in those circumstances in which close visual work is not required, the quantity and quality of illumination are less critical. Although the physical requirements of some specialized classrooms are quite different, the qualities that make for a visually comfortable room remain the same, even though the level and the quality of illumination might be somewhat different. As far as this procedure is concerned, the recommendations are for typical classroom conditions where close visual work is conducted over extended periods of time.

Since the last major revision of the recommendations for school lighting, several advancements have been made in research and lighting design procedures. The new procedures provide a more accurate basis for methods of evaluation. The basic principles of comfort and adequacy apply today as they did in the past. It is still desirable to minimize extremes of luminance, whether they be high or low. Also, the adequacy of lighting in terms of levels of illumination is more completely understood now that more information is available on losses due to veiling reflections in pencil handwriting.

Recent research has shown that losses of visual accuracy because of extremes of luminance within the environment are based on average luminances and their location in relation to the viewer rather than on the maximum luminance of any 1 square inch, except in extreme cases. Small bright areas apparently do not cause any serious loss in vision or comfort unless the luminance in such areas exceeds by three or four times the average room luminance. For the purpose of avoiding undesirable luminance differences, most interior surfaces should be finished with materials of high reflectance. White ceilings with 80 percent reflectance are essential. The upper wall surfaces should be white if possible. If it is desirable to introduce a color, the color should be one of high reflectance. The use of reflectances as high as 80 percent is recommended so that upper walls can be effectively utilized. However, no large areas of wall at heights of less than 7′ (2.13 m) should have reflectances exceeding 50 percent. High reflectance in such areas provides a background that renders faces and objects less bright than the wall and therefore reduces visibility. It is also a potential source of glare. Small areas of chalkboard—less than 10′ (3.05 m) in length—will create no serious loss even if the reflectance is less than 25 percent, but this higher value is more desirable from a comfort standpoint. Tackboards, unlike chalkboards, need not be of low reflectance and should approach the reflectance of the adjacent walls. Colors and textures should be selected by the architect or interior designer to produce an aesthetically pleasing environment. This should and can be done while maintaining reasonably high reflectances, particularly on large areas. Floor materials should have a minimum of 25 percent reflectance so that wide luminance differences are avoided between light colored tasks on the desk and the visually adjacent area of the floor.

Although this document deals basically with electric lighting systems, some of its design considerations also are applicable to systems using daylight as the prime light source. The concern for the conservation of energy in this country has served to bring daylight back as a potential energy source for interior lighting design. If "natural light" is used, it must meet the same fundamental requirements applied to electric light sources: Objectionable glare, poor light distribution, and a general imbalance in the visual environment must be prevented.

Metric equivalents in parentheses are included in parts of the text in conformity with current practice and in anticipation of the conversion to the metric system in this country.

Who Does What?

This section contains descriptions of the responsibilities of the client, Bureau of School Facilities Planning, architect, and engineer.

The Client

Since the design procedure involves judgment and exploration of alternative solutions to the design of the luminous environment, the client, represented by the policymaking and administrative officers of the educational organization for which a facility is being designed, becomes directly involved in decision making, particularly in terms of performance and expenditure priorities.

To ensure the use of the design and evaluation procedure, the client should incorporate a request for its use in the contractual or written instructions to the project architect. As the preliminary design phases of the building plan progress, the architect and the consulting engineer should involve the client in the discussions of the proposed solution or alternative solutions being considered for lighting systems. In this role the client does not need to presume any architectural or engineering competence since the solutions under consideration would be explained to him or her in lay terms.

The client should be especially aware of the modifiers—the factors that may improve or reduce the quality and quantity of any lighting system—and the characteristics that make for the best possible lighting system:

1. Reflectances
   a. Ceilings should be white or light colored, with a reflectance of 80 percent or higher.
   b. Walls should be white or light colored. Their reflectance should be 80 percent or higher above 7′ (2.13 m) and about 50 percent below 7′ (2.13 m). The average reflectance for the total wall should be about 70 percent.
   c. Floors should have a minimum reflectance of 25 percent. A higher reflectance is very desirable, however.

2. Fixture brightness
   a. In a large room the fixtures should be recessed, or the ceiling and lighting system should be designed so that the fixture brightness is not high at angles close to the line of sight.
   b. The brightness of the fixture should be kept low. In a standard two by four fluorescent fixture, more than two tubes will result in a fixture brightness that is too high.

3. Ceiling height

   With a standard recessed ceiling fluorescent fixture, a ceiling height of 12′ (3.66 m) is usually better than a ceiling height of 8′ (2.44 m) since the extra height allows for (1) more wall area for reflectance and, thus, more even distribution of light; and (2) increased comfort since the fixtures are farther from the line of sight. The additional wall area may have a light reflectance of 80 percent or higher.

4. Excess wall luminance (windows)
   a. Window treatment must be such that no direct sunlight falls on the work plane.
   b. Window treatment should allow the entrance of only that daylight necessary to achieve the lighting goals. Excess amounts of daylight cause glare and heat gain.
5. Nonuniformity of illumination (general lighting only)
   a. The fixture type selected and the layout should be compatible with the room design and configuration.
   b. The fixtures should be of such design and manufacture and located at a proper height so that each fixture produces an even pattern of light within its area.
   c. The fixtures should be arranged in a pattern or array that provides for even distribution of the total light throughout the room.
   d. Accent and "effect" lighting should be kept to an absolute minimum.

The client's part in the final decision-making process involves understanding the performance options being considered and the budgetary significance of each alternative. During the decision-making process, questions like those in the example below would be answered. *Example.* The difference between and A and a B rating for visual performance is 15 cents per square foot of instructional area.

1. Does the client wish to increase the construction budget by the 15 cent amount?
2. Could some other element in the proposed plan be changed in quality or quantity to "produce" the 15 cents per square foot?
3. Could some element in the plans be eliminated entirely to produce the needed funds?
4. Is an A rating desirable enough to warrant any change in the plans or budget?

By participating in the final decision-making process, the client will become far better informed about the relative values of many of the building components. The client will also become much more involved in the total planning process and will achieve a better understanding of the educational and cost implications of the various major elements of the facility design.

The Bureau of School Facilities Planning

Education Code sections 39100, 39101, and 81050 (15301 and 15302) require the Department of Education to establish standards for school buildings.[1] They further require the Department to review all plans and specifications for school buildings in every district required to submit plans and specifications to the Department for approval. The Department has placed responsibility for the establishment and administration of these requirements with the Bureau of School Facilities Planning.

It is important to recognize that the Bureau of School Facilities Planning has interpreted the intent of the statutes mentioned above to mean that it should prepare recommendations that may be considered by local authorities during the planning and preliminary phases of each project. Hopefully, as many of the recommendations as possible will be incorporated into each project on the basis of the adequacy of each recommendation in meeting the educational and economic needs of the local jurisdiction.

Upon request, the staff of the Bureau of School Facilities Planning works directly with school officials, architects, and engineers to assist in the planning of educational facilities, preschool through senior high school levels. The ability of the bureau staff to make a

[1] The Education Code was reorganized in 1976. First references are to section numbers as they appear in the reorganized code (Assembly Bill 3100, Chapter 1010, Statutes of 1976, as amended), which became effective on April 30, 1977. Section numbers in parentheses are from the 1973 code as amended.

meaningful contribution requires its early involvement during the planning phase of each project, the development of the district master plan, site selections, and educational programming. The services of the bureau are available to districts even when no formal approval is required.

When formal approvals are required, bureau staff will, following participation during the planning phases, review and evaluate the data presented and approve proposed lighting systems on the basis of both adequate visual comfort and performance.

Staff members will also be available to assist architects, engineers, and school officials with field-test procedures to be used in checking completed lighting installations.

The Architect

The architect is responsible for every phase of a building design but must rely on competent assistance in arriving at final design decisions on each phase. If school lighting installations in general, for example, are to be improved significantly, the planning and budgeting considerations concerning lighting systems must be given more attention and must be understood by architects. This prediction, specification, and evaluation procedure can facilitate the needed understanding if it is used properly in the planning and specification processes.

The architect's responsibility is to see that competent professional engineering skills are applied during the planning phases of a building project. The engineer responsible for the electrical phases of a project should ensure that visual comfort (VCP) and performance standards (ESI) are met in the lighting design for classrooms. VCP is the acronym for visual comfort probability, and ESI is the acronym for equivalent sphere illuminance. The use of the procedure given in this document will be possible only if the architect and electrical engineer maintain close communication during the preliminary planning phases of the design of a project since the engineer must have the information necessary to apply pertinent modifiers, such as surface reflectance factors, location and type of fenestration, and ceiling heights, to any proposed lighting system.

The architect need not be knowledgeable about the technical phases of the procedure, but he or she must understand the effect of building design modifiers that raise or lower the adequacy of a lighting system in terms of both visual comfort and visual performance. He or she also has the final responsibility for whatever lighting decisions are made for a project. The architect's signature, along with that of the professional engineer, on Bureau of School Facilities Planning submittal documents attests to his or her knowledge and approval of the lighting system selected.

The use of the design and evaluation procedure allows the design professions to choose from among several possible lighting designs and make compromises between visual comfort and visual performance so long as the final grade for both categories is acceptable.

The Engineer

The consulting engineer responsible for the lighting design in any given school planning or modernization project represents the real key to obtaining the positive results to be gained from the use of the California school lighting design and evaluation procedure. This procedure basically is an engineering instrument. The other professionals and laypersons involved are completely dependent in their respective roles in decision making on the information that the engineer supplies. The degree to which the engineer follows the outlined procedural steps conscientiously and thoroughly will determine the success or failure of the resultant design.

From the steps presented below, it is obvious that the engineer will need to be in close communication with both the client and the architect from the beginning of the planning.

Only the client can give the engineer some of the information he or she must have, and only the architect can provide other basic design parameters to the engineer.

The design and evaluation procedure covers in complete detail how the engineer approaches and works through each step involved in the design of a proposed lighting system. As the engineer gains experience in the use of this design instrument, he or she will be able to combine or bypass some of the sequential steps presented below:

1. Determine the controlling conditions and the design constraints.
   a. Determine the *task* to be used as a design base.
   b. Determine the *geometry* of the space and of the preferred lighting.
      (1) 2′ x 4′ (0.61 m x 1.22 m) fixtures checkerboard
      (2) 2′ x 4′ (0.61 m x 1.22 m) fixtures in rows
      (3) Luminous ceiling
      (4) 5′ x 5′ (1.52 m) coffers
      (5) Other
   c. Emphasize the following:
      (1) Visual performance
      (2) Visual comfort
      (3) Aesthetics
      (4) Other
2. Set design goals.
   a. Set a goal for the visual comfort probability (VCP) rating or the relative visual comfort (RVC) level.
   b. Set a goal for the equivalent sphere illuminance (ESI) level.
3. Formulate a trial system (select a promising combination of design factors).
   a. Review the existing literature.
   b. Formulate, on a qualitative basis, what the system apparently should be.
4. Determine the VCP rating or the RVC level.
   a. Select a base value.
   b. Determine the applicable modifiers.
   c. Compute the modifiers.
   d. Add the base value and modifiers to obtain a VCP rating or an RVC level.
5. Determine the ESI.
   a. Determine the ESI rating desired.
   b. Estimate or calculate a rough ESI rating.
      (1) Tables for similar systems
      (2) Estimate from system characteristics
6. Compare the determinations with the design goals.
7. Adopt, modify, or redesign the system.
8. Compute the final VCP rating or RVC level.
9. Compute, by computer, the final ESI level.
10. Fill out the basic data and grading form for the proposed lighting system.

Visual Comfort Evaluation

Base Value I

After several years of study and evaluation, a procedure has been refined that takes into account the size, location, and luminance of all areas in the visual environment. After a complex series of computations, a visual comfort probability (VCP) rating can be established that indicates the percentage of people who would be comfortable working in a particular environment. As originally conceived, the method of determining the VCP provided for computations based on recessed luminaires only. However, by an extension, luminous ceilings may also be evaluated. In either case the computations are lengthy, and the best and most accurate method of applying the system is by the use of a computer. Programs have been established and are available in some metropolitan areas. The precise details of the proposed system and environment must be used. These include the lighting characteristics of the luminaire, number and configuration of luminaires, room size, reflectances of all surfaces, and actual level of illumination desired. The rating derived will be an accurate VCP value and will require no modification as far as the electric lighting system is concerned. This *true* VCP rating is considered as Base Value I. Other factors within the environment, independent of the electric lighting, will be described later. Those factors may or may not modify Base Value I.

Other Base Values

When it is not feasible to obtain an actual VCP rating, any of three other methods may be used to establish a "base value," from which a *modified* VCP can be developed. However, one should bear in mind that the VCP method of evaluating the comfort of lighting installations is the accepted method within the lighting profession. When, for convenience, modifications are made to true VCP ratings, the result is called relative visual comfort (RVC) to distinguish between the value established by accepted procedure and that developed by modification of computed values. The other base values are based on accurate VCP computations of comparable lighting systems, and the resulting values correlate closely with a computed VCP based on the same conditions. After one of the four base values has been selected for use, several modifiers must be applied before the final RVC is established. These modifiers and their method of application are described later in this document.

Base Value II

Base Value II is the second most accurate rating. It is established by the use of actual VCP tables supplied by many manufacturers for their particular luminaires. In most cases this information is based on spaces having reflectances of 80 percent for ceiling, 50 percent for walls, and 20 percent for floor cavity, and for 100 footcandles (fc) (1,076 lux). The VCP values are tabulated to show the different ratings for a wide variety of room sizes and ceiling heights. Obviously, these tables must be for the luminaire that is to be used in the proposed design. From these tables one can select the VCP rating for the conditions that most closely match those of the room being evaluated.

Base Value III

When a true VCP rating or a VCP table for the luminaire proposed for use is not available, alternative methods of calculation can be used. Base Value III applies to two basic types of systems: direct luminaires and luminous ceilings. Recessed luminaires or surface-mounted luminaires with less than 15 percent uplight are rated as direct luminaires. The VCP value for direct luminaires in Table 1 is a computed base VCP value for a 30′ x 30′ x 10′ (9.14 m x 9.14 m x 3.05 m) room in which the effective reflectances of the ceiling, wall, and floor cavity are 80, 50, and 20 footlamberts (fl), respectively; the weighted average luminance ($\bar{L}$) of the luminaire is 320 footlamberts (1,096 cd/m^2); and the level of illumination is 70 footcandles (753 lux). It has been found that the VCP for direct luminaires does not change appreciably in a 30′ x 30′ x 10′ (9.14 m x 9.14 m x 3.05 m) room as the level of illumination is varied from 70 to 150 footcandles (753 to 1,614 lux). The method of computing $\bar{L}$ is outlined in Appendix I.

Also included in Table 1 are the VCP ratings for luminous ceilings providing 70, 100, and 150 footcandles (753, 1,076, and 1,614 lux, respectively). These values were computed for the same basic room conditions. As one can see, as the level of illumination is increased from 70 to 150 footcandles (753 to 1,614 lux), the ceiling luminance increases proportionally, and the resulting VCP rating is reduced. These luminous ceiling values apply to totally indirect systems, wall coves, and diffusing luminous ceilings for the calculated values of illumination, with interpolation as necessary. To qualify, a system must cover at least 80 percent of the ceiling area. If this is not the case, the fixtures are considered as direct luminaires and rated accordingly.

Modifiers will be described later for those systems that do not conform to the basic conditions on which base values III and IV are established.

TABLE 1

Computed VCP Ratings for Direct Luminaires and Luminous Ceilings

Fixture	Footcandles (lux)	VCP
Direct luminaires		74
Luminous ceiling	70 (753)	86
Luminous ceiling	100 (1,076)	81
Luminous ceiling	150 (1,614)	74

Base Value IV

The present VCP rating system does not provide for a method of rating surface-mounted luminous-sided units with more than 15 percent uplight or suspended luminaires. For such luminaires extrapolations from the basic VCP data have been made to prepare Base Value IV. (See Table 2.) The VCP can be determined from the following factors:

1. Ratio of uplight to downlight from the luminaire
2. Level of illumination
3. $\bar{L}$ of the luminaires

A close study of the following data shows the effect of each factor as interrelated with the others. The method of computing $\bar{L}$ for both surface-mounted and suspended luminaires is given in Appendix I on page 17.

By one of the four procedures described for establishing a base value, any system of electric lighting applicable to schools can be given a basic value, which is a starting point for determining the final RVC rating.

TABLE 2
Extrapolated VCP Ratings for Surface-Mounted Luminous Sided Units with More Than 15 Percent Uplight and Suspended Luminaires

Up/down distribution	70 fc (753 lx)			100 fc (1,076 lx)			150 fc (1,614 lx)		
	200 fl (685)*	$\bar{L}$ 320 fl (1,096)	440 fl (1,507)	200 fl (685)	$\bar{L}$ 320 fl (1,096)	440 fl (1,507)	200 fl (685)	$\bar{L}$ 320 fl (1,096)	440 fl (1,507)
100/0	86	86	86	81	81	81	74	74	74
80/20	85	83	81	81	79	77	76	74	72
60/40	84	80	77	81	77	74	77	74	71
40/60	84	78	74	82	76	72	78	74	70
20/80	83	76	71	82	75	70	79	74	69
0/100	82	74	68	82	74	68	80	74	68

NOTE: Interpolate as required for $\bar{L}$ and footcandles.

*Numbers in parentheses are candelas per square metre (m^2).

Modifiers

The modifiers described below are applicable to one or more of the base values. A checklist that shows the base values to which each modifier shall be applied is provided on page 13.

Modifier I—Wall Reflectance

Modifier I is the variation from the standard wall reflectances used in the basic calculations. (See Table 3.) The method by which the wall reflectances given below were established is described in Appendix II on page 19.

TABLE 3
Values for Modifier I—Wall Reflectance

Percent of wall reflectance	Modifier
70*	+3
60	+2
50	0
40	−1
30	−3
20	−5
10	−7

*Achieved by high upper wall reflectance only.

Modifier II—Floor Cavity Reflectance

Floor cavity reflectances vary depending on the reflectance of the floor covering and the side walls below the standard 30″ (7.62 cm) table height that is accepted for design purposes as normal for all schoolrooms. It is clear from the data in Table 4 that the floor reflectance is very important in maintaining an acceptable comfort rating.

TABLE 4

Values for Modifier II–Floor Cavity Reflectance

Percent of floor cavity reflectance	Modifier
30	+3
20	0
10	−3

Modifier III–Room Size

The loss of comfort due to increasing the room size from 30′ x 30′ x 10′ (9.14 m x 9.14 m x 3.05 m) to 60′ x 60′ x 10′ (18.29 m x 18.29 m x 3.05 m) can be provided for through application of Modifier III. (See Table 5.) In the larger room more luminaires are in view, and the comfort rating is lower.

TABLE 5

Value for Modifier III–Room Size

Room size	Modifier
60′ x 60′ (18.29 m x 18.29 m)	−3

Modifier IV–Ceiling Height

The comfort rating of all systems changes slightly depending on the ceiling height. (See Table 6.)

TABLE 6

Values for Modifier IV–Ceiling Height

Ceiling height, in feet (and metres)	Modifier
8 (2.44)	−1
10 (3.05)	0
12 (3.66)	+1

Modifier V–Weighted Average Luminance ($\overline{L}$)

The last of the modifiers that applies to the electric lighting system is Modifier V, which pertains to the weighted average luminance (L) of the luminaires being proposed. For base values I, II, and IV, actual luminances were considered. However, Base Value III was established for L of 320 fl (1,096 cd/m^2). Modifiers must be applied if the proposed units are different. In this case Modifier V is established as follows:

$$\text{Modifier V} = \frac{320 \text{ fl} - \overline{L}}{20} = \frac{(1{,}096 \text{ cd/m}^2 - \overline{L})}{(\quad 68.5 \quad)}$$

For example, if the luminaire in question has an $\overline{L}$ of 200 footlamberts, the modifier would be 320 fl − 200 fl ÷ 20 = +6. From this, one can see that the luminaire plays a large part in the visual comfort of any system. Any $\overline{L}$ in excess of 320 footlamberts (1,096 cd/m^2) will result in a negative modifier. (See Table 7.) This modifier should not be applied to luminous ceiling values in Base Value III or luminaires in Base Value IV because these values were determined on the basis of the luminance.

TABLE 7

Values for Modifier V–
Weighted Average Luminance ($\overline{L}$)

$\overline{L}$ in footlamberts	Modifier
200	+6
240	+4
280	+2
320	0
360	–2
400	–4
440	–6

Modifier VI–Excess Wall Luminance

For the VCP and RVC ratings described previously, the sources of high brightness are luminaires installed in or on or suspended from the ceiling. The ratings are based on the overall VCP concept, which takes into account luminance, size, and location. No procedure has been suggested for taking into account high luminances on the walls. The recommendations given below are based on research and experience.

There is ample evidence of measurable losses in visual accuracy because of transient adaptation when the luminance of a large area exceeds five times task luminance. Inasmuch as potential sources of high luminance on the walls are often immediately adjacent to a visual task and may be in or near the line of sight for an extended period of time, it is recommended that areas greater than 1 square foot (0.09 m^2) be limited to five times task luminance. The possibility of an extreme case can be avoided by imposing a limitation of ten times task luminance for any area of 1 square inch (6.45 cm^1) or larger for all wall surfaces.

In the determination of the area of surfaces in which the luminance is higher than task luminance, an area that is less than 3″ (7.62 cm) in its smallest dimension need not be included in the case of the 1 square foot (0.09 m^2) limitation for five times task luminance. This narrow band of luminance must not exceed the limitations for areas of 1 square inch (6.45 cm^2) or larger. If surfaces on walls exceed these limitations, a two-point negative modifier must be applied for each full number multiplier in excess of the limitation. (See Table 8.) For example, a source greater than 1 square foot (0.09 m^2) in area, which is seven times task luminance, would call for a four-point negative modifier, two points each for the two whole numbers over 5. Obviously, areas of high luminance that are larger in size than those mentioned will create poorer conditions and should be further penalized. However, no additional negative modifiers are included at this time.

TABLE 8

Values for Modifier VI–Excess Wall Luminance

Excess wall luminance	Modifier
Over 1 square foot (0.09 m^2)	–2 per whole number over 5
Over 1 square inch (6.45 cm^2)	–2 per whole number over 10

Modifier VII–Window Luminance

The system of evaluating for comfort has been, to this point, directed specifically at the electric lighting system and room reflectances. Other potential sources of glare are the windows. Their luminance, large area, and extremely important location, often in the direct line of sight of many or all students, make them a major factor for consideration. The principles that determine comfort apply to daylight as well as to electric light sources, and for this reason the maximum luminance of any area viewed through a window is limited to five times task luminance. The methods of luminance control are dependent on the circumstances of the specific locations; and the desired result might be achieved by well-placed trees, fixed shielding devices, or low-transmission glass. If adjustable shielding devices are used for window light and glare control, they must be mechanically controlled so that they do not expose the sky brightness to the students. If this is not the case, and the devices are capable of being improperly adjusted, the sky brightness of 2,000 footlamberts (6,850 cd/m^2) shall be used as an average. In all cases an additional two-point negative modifier must be included if no provision is made to exclude direct sunlight from the room during normal daytime school hours. (See Table 9.) The glare created within a classroom by direct sunlight, even through low-transmission glass, is intolerable, and every effort must be made to prevent it.

TABLE 9

Values for Modifier VII–Window Luminance

Window conditions	Modifier
Luminance limit, over 1 square foot (0.09m^2)	–2 per whole number over 5
Direct sunlight into the room	–2

Modifier VIII–Nonuniformity of Illumination

One other lighting system characteristic that is of importance in classrooms is the uniformity of the illumination level. Since task luminance is a factor in both visual comfort and visual performance, it is important that the illumination level not vary greatly throughout the seating area of the room.

If the task luminance at the point in the room with the lowest level of illumination is less than 70 percent of its value at the point where the visual comfort is calculated, one can expect that both visual comfort and transitional adaptive effects will be measurably affected because of the lower luminance at that location. Research indicates that changes in visual comfort as high as 6 percent can be expected with a drop to 70 percent of the average illumination. Therefore, any variation in excess of this value should be penalized. A modifier of –3 is to be added to the RVC computation if the illumination at the lowest point in the normal seating area (anywhere more than 4′ (1.22 m) from the walls) is less than 70 percent of the average. (See Table 10.) These values can be calculated as described in Appendix III on page 20.

TABLE 10

Value for Modifier VIII–Nonuniformity of Illumination

Nonuniformity of illumination	Modifier
Minimum illumination less than 70 percent of average illumination	–3

Modifier IX–Maximum-to-Average Luminance Ratio

Luminaires should have a maximum-to-average luminance ratio not to exceed 5:1 at angles of 45°, 55°, 65°, 75°, and 85° from nadir. If the luminaire exceeds this ratio, a modifier of –1 shall be added to the base values for each of the above angles at which this ratio is exceeded. (See Table 11.)

TABLE 11

Value for Modifier IX—Maximum-to-Minimum Ratio

Luminance ratio	Modifier
Exceeds 5:1 luminance ratio at angles of 45°, 55°, 65°, 75°, and 85° from nadir	−1

Summary

The system of RVC calculation can be summarized as follows. A base value is obtained and then adjusted by modifiers that account for variations from the base conditions. Chart 1 is a checklist of the nine modifiers. It indicates the base values to which each must be applied if such modification is required by the concept being evaluated.

Step-by-step explanations of how to determine the final RVC ratings from the four base values and the nine modifiers are included in Appendix IV.

CHART 1

Modifier Checklist

Modifier	Quality	Base values I	II	III	IV
I	Wall reflectance		X	X	X
II	Floor cavity reflectance		X	X	X
III	Room size			X	X
IV	Ceiling height		X	X	X
V	$\bar{L}$ (weighted average luminance)			X*	
VI	Excess wall luminance	X	X	X	X
VII	Window luminance	X	X	X	X
VIII	Nonuniformity of illumination	X	X	X	X
IX	Maximum-to-average ratio	X	X	X	X

*Does not apply to luminous ceilings in Base Value III.

Field Evaluation

Because of the complexity of the variations in the luminous environment, no meters are available to measure visual comfort directly. For this reason a procedure has been developed for use in determining compliance between the suggested design and the completed project. This procedure is described in Appendix V.

The many interrelated factors that affect visual comfort make it most difficult to evaluate accurately each element of the visual environment. The recommendations in this document provide reasonable values based on accepted practices and basic research. The desired result is a visual environment in which there are no excessive luminances; that is, no luminances that are excessively higher or lower than that of the task. One must apply good judgment and reason in making an evaluation. If this is done honestly, with the design goals kept in view, the rating will be sound. If, on the other hand, every point of the evaluation is stretched to its ultimate and every loophole is used to its greatest advantage, the results may be unfortunate.

A major advantage of the procedure is that it requires the engineer and architect to work together during the design stage—to make decisions and recognize their ultimate effect. The procedure allows credit for characteristics that are better than normal to provide a better-than-average environment or to compensate for any negative aspects. In any case, the overall effect of the many decisions can be evaluated during the design period and can be confirmed when the project is completed.

Visual Performance Evaluation

The required levels of illumination for visual accuracy depend on the size of the task and the apparent contrast within the task. A well-printed book, an original document typed with a good ribbon, and ink handwriting all require less than two footcandles (21.5 lux) to be seen with the same visual accuracy that would require 133 footcandles (1,431 lux) for a fifth copy typed carbon, or 589 footcandles (6,338 lux) for a poor quality thermal reproduction. Pencil handwriting has been generally accepted as a standard for the determination of classroom lighting requirements, and the level of illumination recommended for reading pencil handwriting is 70 footcandles (753 lux) of sphere quality illumination.

Sphere quality illumination, or ESI footcandles, pertains to the degree to which light is provided to the task equally from all directions, as though the task were placed in the center of a uniformly lighted sphere. This specification is essential for pencil handwriting because the specular quality of the graphite line on paper is such that the contrast between the line and its background changes radically under different lighting systems. In extreme cases where there is a higher concentration of light to the task from the critical area overhead and in front of the viewer, the pencil line appears brighter than the paper. In cases where most of the light to the task comes from low angles, from the sides and rear rather than from overhead, the contrast in the pencil task appears greater. Consequently, fewer footcandles would be required from a system that provides light in this manner.

The findings from recent studies in many classrooms indicate the extreme importance of lighting quality and its relationship to lighting levels. For example, in one room the actual level of illumination on the task was 135 footcandles (1,453 lux), but the quality of illumination was only 18.3 ESI footcandles. At the other extreme, a room in which the level of illumination was only 16 footcandles (172 lux) had a sphere quality illumination of 29.9 footcandles. In neither case did the illumination approach the 70 ESI footcandles (753 lux) recommended for classrooms.

Contrast is dependent upon the distribution of light flux within the room, the amount of flux, and the directions from which the flux falls on the task. For typical classroom tasks illumination from an area directly in front of the task causes reflections that obscure, or "veil," one's vision and make the task difficult to see. Illumination from other areas within the room is much more effective in increasing or maintaining the task contrast. Effective system design for visual performance, therefore, involves reducing or eliminating flux from the area directly in front of the task by controlling the location of luminaires, the distribution of light from them, or the quality of the light (polarization) itself. Attention to these characteristics makes it possible to estimate the effectiveness of a system prior to making an accurate determination by computer. Stated simply, it is important to get as much of the illumination as possible to a point from sources that do not cause veiling reflections.

Recent studies of classroom lighting systems have also shown that many installations meet all of the comfort requirements but that few provide adequate sphere quality illumination. Careful study of the basic concepts of light distribution, luminaire specification, and placement in the room must be made to provide the required combination of comfort and performance.

Under unusual circumstances a system may be designed that will have a contrast rendition factor greater than 1.00, providing an ESI rating that is higher than the conventional footcandle level. In consideration of the many visual tasks performed in classrooms, other than ESI-sensitive tasks, it is recommended that the average illumination level for general-lighting systems be at least 50 footcandles (538 lux), regardless of the ESI rating.

Particularly for cases in which task-oriented lighting is used, it is possible to design systems with a very high contrast rendition factor (CRF). The validity of the flux-contrast system is suspect in such cases, however. Therefore, if the ESI exceeds the illumination level by 50 percent or more, its validity should be questioned.

In conclusion, the specific values established for the VCP or RVC ratings and the methods of determining ESI make possible the conduct of a preliminary visual evaluation. (See tables 12 and 13.) Because of the completely different factors that affect comfort and the qualities that provide for accurate seeing, comfort and performance must be considered separately and must be recognized to be of equal importance.

TABLE 12

Comfort Grading Scale

VCP or RVC rating	Grade
85 or more	A
75 to 84	B
65 to74	C
55 to 64	D
Less than 55	F

TABLE 13

Performance Grading Scale

ESI rating	Grade
55 or more	A
45 to 54	B
35 to 44	C
25 to 34	D
Less than 25	F

Alternative Visual Performance Design: Task-Oriented Classroom Lighting Systems

The Bureau of School Facilities Planning encourages the use of lighting systems that provide high levels of visual performance while using as little energy as possible. In such cases system designs that produce lighting oriented to the task position may be utilized in place of general lighting. Designers who wish to use such a system should work closely with the staff of the Bureau of School Facilities Planning. The following are the characteristics recommended for a complete task-oriented system:

1. The system should be capable of producing an ESI rating of at least 50 for specific areas within the classroom. The remainder of the area should have a minimum (non-ESI) footcandle level of 30.
2. The system should be capable of producing, in a specific viewing direction, an ESI rating of at least 50 over an area at least 4′ (1.22 m) square.
3. The system should be capable of producing simultaneously not less than one such area for each 100 square feet of room area.
4. The system should be capable of performing as described above at any point, within the classroom, that is more than 3′ (0.09 m) from the walls.
5. The system should meet all of the visual comfort evaluation requirements except those for nonuniformity of illumination (Modifier VIII).
6. The system should be such that one person can change the configuration to another configuration.

Appendix I
Calculation of $\bar{L}$

$\bar{L}$ (the weighted average luminance of a luminaire) will, in most cases, be available from the luminaire manufacturer. If not, it can be computed, by one of the following methods, on the work sheet on page 27.

1. Average luminances of the luminaire available:
   a. Determine the luminaire average luminances in the column labeled "Average L (ftl)."
   b. Multiply the average luminances by the values in the column labeled "T."
   c. Add the values from the "L X T" column. The sum is the $\bar{L}$.
   d. Compute the flux ratio test as shown at the bottom of the work sheet, and correct $\bar{L}$.
2. Candlepower distribution of the luminaire in three planes available:

   Calculate the average luminance of the luminaire at each angle by means of the following equation:

   $$\bar{L}\text{ footlamberts} = 452\,\frac{I}{Ap}\quad\left(L_{cd/m^2} = \frac{I}{Ap}\right)$$

   $\bar{L}$ footlamberts ($\bar{L}_{cd/m^2}$) is the average luminance in footlamberts (cd/m^2), I is the candlepower of the luminaire at the given angle, and Ap is the projected area of the luminaire in square inches (square metres). The calculation is done as follows:

   (1) For all recessed luminaires with flat or regressed panels, Ap = L X W X cos θ, where L is the length, W is the width, and θ equals the angle from nadir.

   (2) For all recessed luminaires with drop panels and all surface luminaires with less than 15 percent uplight, Ap = L X Wp, where Wp is the projected width of the luminaire only, at the angle being measured.

   (3) For all luminaires with more than 15 percent uplight, surface-mounted or suspended less than 3″ (7.62 cm), Ap = L X Wp, where Wp is the projected width of the luminaire plus the ceiling directly above the luminaire of 150 fl (514 cd/m^2) or more in luminance. In this case photometric data must be available for the luminaire.

   (4) For all luminaires suspended more than 3″ (7.62 cm) from the ceiling, calculate the same as for (2) above.

   Note that, in general, $\bar{L}$ will be the same for transverse and parallel viewing directions. The higher of the two values should normally be used to allow for viewing in any direction. Note also that all calculations must be made for initial conditions.

   A complete discussion of $\bar{L}$ and its associated system may be found in the *Journal of the Illuminating Engineering Society*, April, 1972, page 256 ff.; and October, 1973, page 31 ff.

Example

A luminaire is to be used whose luminances are as shown in Figure 1 on page 28 and whose 0–60° and 60–90° fluxes from photometric data are 4,485 and 1,513, respectively. The weighted average luminance, $\bar{L}$, is to be determined for the crosswise viewing direction.

The luminances are read from the curves and entered on the work sheet on page 27. These values are multiplied by the multipliers (T) and summed to obtain the $\bar{L}$, which in this case is 400.0.

The correction factor ϕ (flux) is obtained from Table 14, "Correction Factor ϕ Table for Obtaining $\phi\bar{L}$ When Ratio B Is Less Than 4 and Greater Than 10," after determination of the flux ratio B:

$$B = \frac{\text{Flux } 0\text{–}60}{\text{Flux } 60\text{–}90} = \frac{4{,}485}{1{,}513} = 2.96$$

The correction factor is found to be 1.38. The corrected value for $\bar{L}$, then, is:

$$\bar{L}_{corr} = 1.38 \times 400 = 552.$$

TABLE 14

Correction Factor Ø Table for Obtaining Ø$\bar{L}$ When Ratio B Is Less Than 4 and Greater Than 10

B	Ø
1	2.34
2	1.68
3	1.38
4	1.20
5	1.08
6	0.990
7	0.920
8	0.862
9	0.815
10	0.775
12	0.710
14	0.659
16	0.618
18	0.584
20	0.556
30	0.457
40	0.398
50	0.358
60	0.328
70	0.304
80	0.286
90	0.270
100	0.257

Appendix II
Averaging of Wall Reflectances

The usual assumption of uniform wall reflectance will nearly always be inadequate. In most cases it will be necessary to know the average reflectance of all wall surfaces taken together. To determine this, first multiply the area of each wall surface by its reflectance. Then add the surface areas, and divide by the area of the wall:

$$p_{av} = \frac{A_1 \, p1 + A_2 \, p2 + \ldots\ldots A_n \, pn}{A_w}$$

For example, suppose one wall of a classroom 30′ (9.14 m) long with 7½′ (2.29 m) from work plane to ceiling cavity plane contains two chalkboards with a reflectance of 12 percent and an area of 60 square feet (5.47 m^2) and one tackboard with a reflectance of 40 percent and an area of 40 square feet (3.11 m^2). Suppose, too, that the remainder of the wall is painted so that it has a 65 percent reflectance. Thus:

Chalkboards:	0.12 X 60 =	7.2
Tackboard:	0.40 X 40 =	16.0
Wall:	0.65 X 125 =	81.25
	A x p	= 104.45

$$p_{av} = \frac{104.45}{225} = 0.464 = 46.4 \text{ percent}$$

If the other three walls have average reflectances of 38.2 percent, 57.5 percent, and 34.6 percent, the average of all walls is:

$$p_{av} = \frac{38.2 + 57.5 + 34.6 + 46.4}{4} = 44.2 \text{ percent}$$

Windows are not counted in determining average wall reflectance since their effect is variable and is accounted for in Modifier VII.

Appendix III
Calculation of Uniformity of Illumination

The degree of uniformity of illumination can be calculated as follows:

1. Select the point of lowest illumination in the seating area. This point can usually be selected by inspection of the design plan.
2. Calculate the illumination at this point by any applicable standard method.
3. Calculate the average illumination by the standard zonal-cavity method.
4. Divide the illumination at the low point by the average illumination. If the figure thus obtained is less than 0.70, deduct three points from the base values as shown for Modifier VIII on page 12, or revise the system to improve the uniformity.
5. If the luminaires do not at any point exceed the rated spacing-to-mounting height ratio for the luminaire involved, it may be assumed that the system meets the 0.70 minimum-to-average criterion, and no computations need be made.

Appendix IV
Calculation of RVC

The relative visual comfort, or RVC, is related to the visual comfort probability (VCP). If a VCP for the specific conditions of the installation is available, it should be used in preference to calculating an adjusted base value from bases II, III, or IV, which will be similar to the VCP but not necessarily identical in value.

There are four methods of obtaining a base value for a given installation. They are described below in the order of their accuracy with respect to the VCP. The most accurate is described first.

1. Obtain a VCP for the exact conditions of the installation (Base Value I). This may be obtained by means of available computer services or may be calculated by hand (See *Illuminating Engineering,* October, 1966, pp. 634 and 643).
2. Select a VCP value for standard conditions (usually 80 percent ceiling, 50 percent walls, and 20 percent floor cavity, 100 footcandles [1,076 lux]) from a table for the luminaire used (Based Value II).
3. Obtain a Base Value III as follows:
   a. For all recessed or surface-mounted units with less than 15 percent uplight, use the "direct unit" value.
   b. For totally indirect, cove, and diffusing luminous ceiling systems, use the "luminous ceiling" value for the calculated illumination level, interpolating as necessary. To qualify, the system must cover at least 80 percent of the ceiling area. If the coverage is less than 80 percent or if the ceiling luminance when viewed at 45° is more than two times the luminance of the same area viewed at 75°, treat the system as an individual fixture system as in the first method described above.
4. Obtain a Base Value IV as follows (use Base Value IV for all pendant systems or surface-mounted systems with more than 15 percent uplight):
   a. Calculate $\bar{L}$ for the luminaire in the parallel and transverse directions. Use the higher $\bar{L}$ of those determined. Use the procedure given in Appendix I and the data from the work sheet to calculate $\bar{L}$.
   b. Select the line in the table nearest the fixture uplight/downlight distribution, and determine the base value for the illumination level and luminaire $\bar{L}$ to be used, interpolating as necessary.

After determining the initial base value by one of the four methods described above, establish the applicable modifiers as shown on the checklist on page 13, and add the values to the base value. The final RVC may be higher or lower than the original base value, depending on the total effect of the modifiers.

Example 1

In a proposed system 2′ x 4′ (0.61 m x 1.22 m) recessed luminaires with low brightness lenses are to be used in a 30′ x 30′ room with a 10′ ceiling (9.14 m x 9.14 m x 3.05 m). The reflectances are to be 80 percent on the ceiling, 50 percent on the walls, and 20 percent from the floor cavity. The level of illumination will be 100 footcandles, and from the published tables provided by the manufacturer, the VCP is found to be 74.

The room size, reflectances, and level of illumination are the same as those on which the VCP table is based; consequently, the first five modifiers do not apply.

a. The VCP rating provided by the manufacturer is 74
b. Modifier VI: There will be no excessive wall luminances; therefore, modifier VI is 0
c. Modifier VII: The north-facing windows are to have glass with a 50 percent transmission. The sky brightness seen through the windows will be 1,000 footlamberts, the task brightness will be 70 footlamberts, and the window-to-task luminance ratio is 14.3:1. The

addend, as described in Modifier VII, is a negative two points for each full multiplier over five, which means $-2 \times (14.3-5)$ or	−19
d. The minimum level of illumination with the proposed spacing of luminaires will be less than 70 percent of the average. The modifier for this circumstance is	− 3
e. The manufacturer's photometric data show that the maximum luminance at 45° is six times the average at that angle. In accordance with Modifier IX, this requires an addend of	− 1
Thus, the RVC rating is 51, and the grade is F.	51

Example 2

In a proposed system surface-mounted luminaires with 10 percent uplight are to be installed in 60′ x 60′ rooms with 12′ ceilings (18.29 m x 18.29 m x 3.66 m). The ceiling is white with 80 percent reflectance; the average reflectance of all four walls is 60 percent; and the floor cavity reflectance is 23 percent. The illumination level will be 120 footcandles. The $\bar{L}$ has been computed to be 380 footlamberts. The VCP for surface-mounted luminaires is taken from Base Value III, direct luminaires, and is found to be 74.

a. The VCP is	74
b. Modifier I (60 percent wall reflectance) is	+ 2
c. Modifier II (23 percent floor cavity reflectance) is	+ 1
d. Modifier III (60′ x 60′ [18.29 m x 18.29 m] room) is	− 3
e. Modifier IV (12′[3.66 m] ceilings) is	+ 1
f. Modifier V $\frac{(320-380)}{20}$ is	− 3
g. Modifier VI (excess wall luminance) is	0
h. Low-transmission glass provides direct glare control, *but* sunlight enters the west rooms. Modifier VII is	− 2
i. The minimum level is more than 70 percent of the average. Modifier VIII is	0
j. The maximum luminances at all angles of viewing are less than five times the average. Modifier IX is	0
The RVC rating is 70, and the grade is C.	70

Example 3

Semi-indirect luminaires with 60 percent uplight and 40 percent downlight are to be mounted 8′ (2.44 m) above the floor in 30′ x 30′ x 12′ (9.14 m x 9.14 m x 3.66 m) rooms. The ceiling reflectance is 80 percent, the average wall reflectance is 40 percent, and the floor cavity reflectance is 30 percent. The level of illumination is to be 90 footcandles, and the $\bar{L}$ has been computed to be 450 footlamberts.

The base value is taken from Base Value IV, and by means of interpolation for 90 footcandles, the value is found to be 75. (No reduction is made for the slight difference between 440 $\bar{L}$ and 450 $\bar{L}$.)

a. The VCP is	75
b. Modifier I (40 percent wall reflectance) is	− 1
c. Modifier II (30 percent floor cavity reflectance) is	+ 3
d. Modifier III (room size) is	0
e. Modifier IV (ceiling height) is	+ 1
f. $\bar{L}$ has been included in Base Value IV value. Modifier V is therefore	0
g. Modifier VI (excess wall brightness) is	0
h. The windows are glazed with low-transmission glass, and the roof overhangs provide shielding from direct sunlight. Modifier VII is	0
i. Modifier VIII (nonuniformity of illumination) is	0
The RVC rating is 78, and the grade is B.	78

From the three examples one can see that each of the modifiers has a definite bearing on the overall quality of the proposed lighting systems. In each case the requirements for raising the evaluation score are evident.

Appendix V

Field Evaluation of VCP or RVC

No instrumentation is currently available for making a visual comfort evaluation in the field. However, it is possible to measure the parameters and compare them to those used in the design. This approach is particularly appropriate when changes from the design have been made; for example, a substitute luminaire has been used or a carpet of a different color and a different reflectance has been furnished.

Since measurement of luminaire average brightness, or $\overline{L}$, is not practical in the field, it is suggested that the luminaire used in the installation be compared with its description in the photometric data report, particularly with respect to the type of light control panel, lamp used, dimensions, and finishes. A further check can be made by measuring the maximum luminance at some angle reported in the photometric data and comparing this value with the reported one. Should the measured luminance be substantially higher than that reported in the data, one may assume that the luminaire is not as described in the data. Such measurements must be conducted with care, particularly in the area "received" by the meter, which must be 1 square inch (6.45 cm^2). It should also be noted that the luminaire luminance will be increased by reflection from the room surfaces. While for lensed luminaires this will not normally result in an appreciable percentage increase, in the case of diffusing units—particularly those of low average luminance—the bottom panel luminance may be increased significantly. This increase must not be taken as an indication of nonconformity with the specifications. Its magnitude will usually be approximately equal to the floor luminance, which may be subtracted from the luminaire value to find the true luminance. Alternatively, in the case of a recessed system, the ceiling halfway between the fixtures may be measured and this value subtracted from the luminaire reading. As an alternative, the fixture being tested may be turned off, and its luminance from only reflected light can be measured.

Reflectance measurements in the field are most readily made by comparing the luminance of the surface to be measured to that of a sample of known reflectance held at the same point. The luminance readings are then proportional to the reflectances. Care should be taken that such measurements are not made at angles at which light may be reflected semispecularly from the surface.

Appendix VI
Calculation of ESI

The ESI rating shall be that value that is provided by the lighting system for the standard school task (pencil handwriting), viewed at an angle of 25°, on 85 percent of the work area for random viewing directions. The statistical tolerance level shall be 99 percent.

The ESI rating shall be calculated in accordance with the recommendations of the Illuminating Engineering Society in its *Recommended Practice for the Specification of an ESI Rating in Interior Spaces When Specific Task Locations Are Unknown.* The procedure for calculation is as follows:

1. Select a typical classroom. This should be the room that is most common in size and shape. If the area of the room exceeds 900 square feet (83.61 m^2), a section this size or smaller, divided along logical partitioning lines, shall be used.
2. Determine a computational grid in accordance with the guidelines in *Recommended Practice for the Specification of an ESI Rating in Interior Spaces When Specific Task Locations Are Unknown.* Note that the spacing of the grid points must not exceed one-fifth of the distance from the work plane to the luminaire (or the ceiling if the ceiling is the light source). It is recommended that a spacing of 1′ (0.30 m) be used. The computational grid must cover all portions of the classroom area that are 3′ (0.91 m) or more from the walls or extremities of the area. Small irregularities of the wall may be ignored.
3. Calculate the ESI values for all points on the grid for four orthogonal lateral viewing directions (north, south, east, and west, for example). Note that if the system is bilaterally symmetrical, only half of the points need be computed; if it is quadrilaterally symmetrical, only one-fourth need be computed.
4. Determine the ESI value attained or exceeded over 85 percent of the grid. This value is the ESI rating for the installation. Note that since all points on the grid are computed, the statistical tolerance level is automatically 99 percent. The random sampling procedure in *Recommended Practice for the Specification of an ESI Rating in Interior Spaces When Specific Task Locations Are Unknown* may be used in this determination if a system is completely asymmetrical and thus requires an excessive number of computations. In this case the statistical tolerance level must be at least 95 percent.

For schools that are planned for daylight use only, the "contribution" of the daylighting system to the ESI requirement may be included. Calculations should be based on the common-worst daylighting conditions for the particular location and orientation of the classroom. Computer programs for this computation are currently being developed. The use of daylighting to provide as much as possible of the required illumination, commensurate with heat gain/loss requirements, is strongly recommended. Switching should be utilized to supplement daylight when necessary and to provide for rated conditions during night use.

Providing lighting systems with different ratings for day use and night use may be desirable in some instances.

Example

A room is 30′ x 30′ with a ceiling height of 9′ (9.14 m x 9.14 m x 2.75 m). The ceiling reflectance is 80 percent, the wall reflectance is 50 percent, and the floor cavity reflectance is 20 percent. The luminaires are 2′ x 4′ (0.61 m x 1.22 m) fluorescent recessed, two lamps each, equipped with panels designed for the production of high ESI. The luminaires are 20 in number, arranged 6′ x 8′ (1.83 m x 2.44 m) on centers.

The computational grid is selected to begin 3′ (0.91 m) from the wall on all sides. Since the room is quadrilaterally symmetrical, calculations are carried out for only one-fourth of the room, at the center of each 1 square foot (0.09 m^2) of area.

ESI and footcandle values are given in the computer readout for each location and for all four viewing directions. The computer then determines that the ESI is equaled or exceeded at percentages of the computed points from 70 percent to 99 percent and tabulates them. The tabulation shows that the ESI rating for 85 percent of the work stations is 44. The grade is therefore a very high C. The use of a higher lumen lamp or a more efficient luminaire or some other modification could improve the system enough to warrant rating it in the B category.

Appendix VII
Measurement of ESI

One method of measuring ESI for the pencil task and 25° viewing angle is by the use of a visual task photometer. Two other instruments—one visual and one photoelectric—can also be used. However, neither of the two instruments is currently being produced commercially, and the use of a visual task photometer is generally impractical.

In place of direct measurement, the following procedure may be used for verifying the attainment of calculated performances. The only instrument required is an illumination meter. This meter should be accurate within plus or minus 5 percent and linear within 2 percent. A linear scale meter is desirable. The meter must be accurately cosine corrected.

1. Verify that the geometry of the system is as determined in the computations. The locations and dimensions of the luminaires, the room dimensions, and the reflectances may be determined either visually or by means of a simple measurement.
2. Verify that the luminaire characteristics are as reported. Essentially, this consists of verifying that the luminaires actually used on the job are those for which the computations were made.
3. Measure the illumination at several of the calculated points. If the illumination is as calculated and the verifications described in steps 1 and 2 have been made, the actual ESI should be about the same as the calculated ESI.

Appendix VIII
Additional Technical Data

Work Sheet for Computing $\overline{L}$

(Data are for Luminaire XYZ viewed crosswise.)

Angle from nadir in degrees		Average L (ftl)	T	L X T
Viewing direction	85	250	0.0375	9.4
	80	305	0.1080	33.0
	75	355	0.0884	31.3
	70	390	0.0703	27.4
	65	420	0.0543	22.8
	60	435	0.0406	17.7
	55	440	0.0312	13.7
	50	445	0.0229	10.2
	45	445	0.0159	7.1
	40	440	0.0102	4.5
			Total	177.1
Diagonal (45°)	85	305	0.0203	6.2
	80	355	0.1065	37.8
	75	415	0.1022	41.4
	70	455	0.0841	38.3
	65	480	0.0681	32.7
	60	490	0.0507	24.8
	55	485	0.0333	16.1
	50	480	0.0214	10.2
	45	475	0.0109	5.2
	40	470	0.0021	1.0
			Total	213.7
90° to viewing direction	80	380	0.0046	1.7
	75	440	0.0096	4.2
	70	475	0.0052	2.5
	55	495	0.0017	0.8
			Total	9.2
			TOTAL $\overline{L} = L \times T = 400.0$	

Flux ratio test:

$$B = \frac{\text{Flux} \quad 0\text{–}60}{\text{Flux} \quad 60\text{–}90} = \frac{4{,}485}{1{,}513} = 2.96$$

If less than 4.0 or greater than 10, multiply by factor $\phi = 2.34\ (B^{-.48})$.

$\phi = 1.38$

See Table 14, page 18.

$\overline{L}$ corrected = 400 x 1.38 = 552

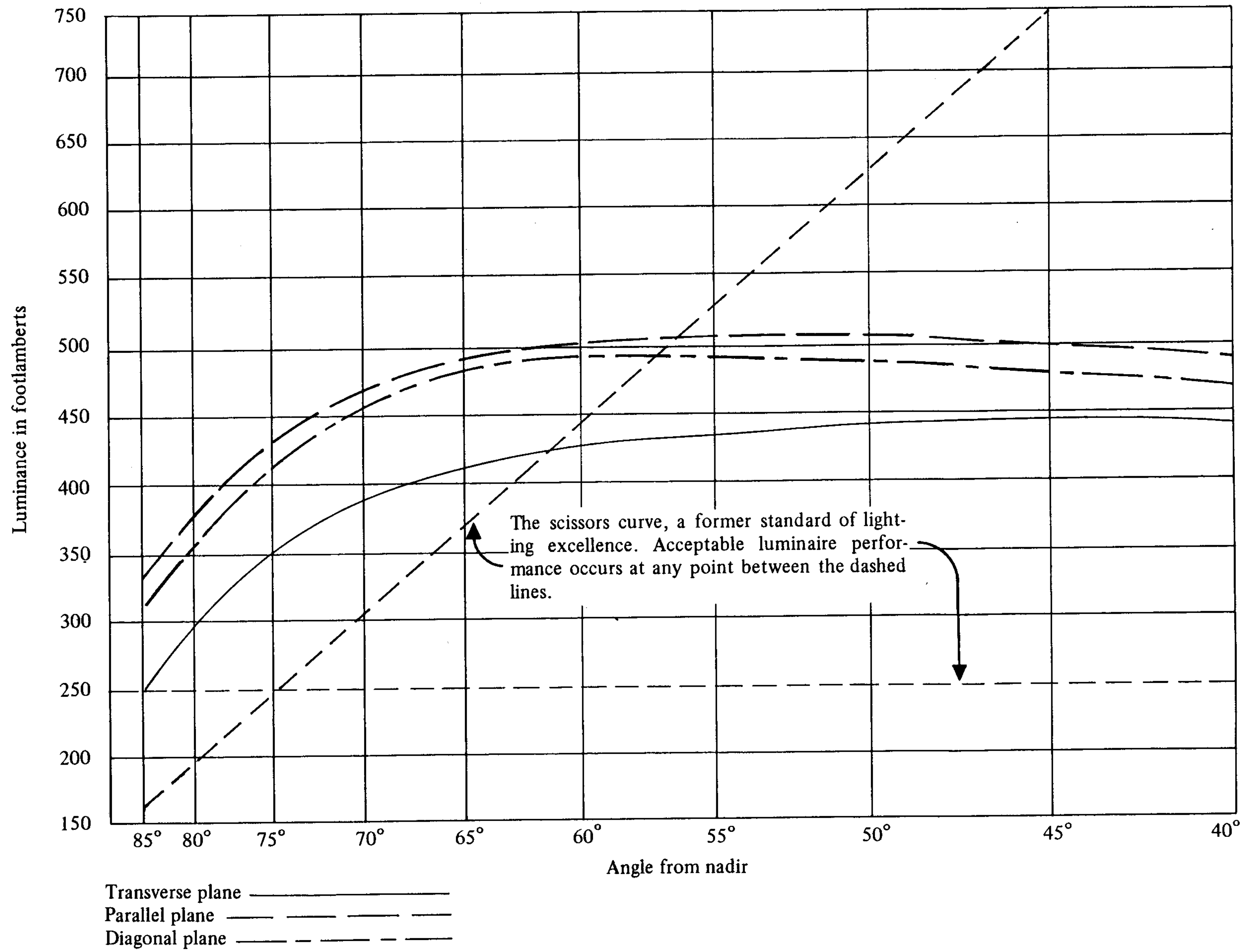

Fig. 1. Average luminance for Luminaire XYZ

SAMPLE

Basic Data and Grading Form for Proposed Lighting System

School district ______________________ Date ______________________
Authorized agent ______________________ Architect ______________________
School ______________________ Engineer ______________________
Address ______________________

The evaluation procedure is based, in part, on the following data:

1. Room size ______________

2. Average reflectances:

   a. Ceiling ______________ c. Right wall ______________ e. Left wall ______________
   b. Front wall ______________ d. Rear wall ______________ f. Floor ______________

3. Luminaire data:

   a. Manufacturer ______________________
   b. Catalog number ______________________
   c. Number and type of lamps per luminaire ______________________
   d. Brief description of luminaire ______________________
   ____

Visual comfort

1. Provide computed VCP if Base Value I is used: ______________________
   Provide value from VCP table if Base Value II is used: ______________________
   Provide computed value of $\overline{L}$ if Base Value III or Base Value IV is used: ______________________
2. On the reverse side of this form, enter in Table I the applicable base value and the selected or computed values for the appropriate modifiers. Add all figures in the applicable column to determine the RVC. (Be sure to use only *one* vertical column.)

Visual performance

1. Prepare a drawing that shows the following:
   a. Room shape and dimensions
   b. Average reflectances of each wall, the ceiling, and the floor
   c. Locations and dimensions of luminaires
   d. Location of grid for ESI computations and spacing of points
2. Provide the manufacturer's photometric data for the proposed luminaire.
3. Provide computer data for CRF-ESI computation if any system other than that outlined in Appendix VI is used. If the latter is used, fill in Table II on the reverse side of this form, or provide a computer computation.

TABLE I

	Base Value I	Base Value II	Base Value III	Base Value IV
Modifier I	______	______	______	______
Modifier II	______	______	______	______
Modifier III	______	______	______	______
Modifier IV	______	______	______	______
Modifier V	______	______	______	______
Modifier VI	______	______	______	______
Modifier VII	______	______	______	______
Modifier VIII	______	______	______	______
Modifier IX	______	______	______	______
Total	______	______	______	______

TABLE II

		Viewing direction (W1 or W2)
1. Average initial FC (E_t)	______	
2. E_{vr} (total)	______	
3. Percent E	______	
4. ESI	______	

Grades

	Actual value	Grade
Visual comfort (VCP or RVC)	______	______
Visual performance (ESI)	______	______

Engineer's signature ______ Architect's signature ______

Date ______ Date ______

SAMPLE

Basic Data and Grading Form for Proposed Lighting System

School district Central City
Authorized agent John Q. Agent
School Central High
Address 1st. and A Sts., Central City, CA

Date January 30, 1975
Architect Drawing and Drawing
Engineer Watt and Amp

The evaluation procedure is based, in part, on the following data:

1. Room size 30' x 30' x 9'
2. Average reflectances:
   a. Ceiling 80
   b. Front wall 50
   c. Right wall 50
   d. Rear wall 50
   e. Left wall 50
   f. Floor 20
3. Luminaire data:
   a. Manufacturer ABC
   b. Catalog number 000
   c. Number and type of lamps per luminaire Two F40 CW
   d. Brief description of luminaire 2x4 recessed luminaire with high-ESI acrylic panel

Visual comfort

1. Provide computed VCP if Base Value I is used: ______
   Provide value from VCP table if Base Value II is used: ______
   Provide computed value of $\overline{L}$ if Base Value III or Base Value IV is used: 315
2. On the reverse side of this form, enter in Table I the applicable base value and the selected or computed values for the appropriate modifiers. Add all figures in the applicable column to determine the RVC. (Be sure to use only *one* vertical column.)

Visual performance

1. Prepare a drawing that shows the following:
   a. Room shape and dimensions
   b. Average reflectances of each wall, the ceiling, and the floor
   c. Locations and dimensions of luminaires
   d. Location of grid for ESI computations and spacing of points
2. Provide the manufacturer's photometric data for the proposed luminaire.
3. Provide computer data for CRF-ESI computation if any system other than that outlined in Appendix VI is used. If the latter is used, fill in Table II on the reverse side of this form, or provide a computer computation.

TABLE I

	Base Value I	Base Value II	Base Value III	Base Value IV
Modifier I			0	
Modifier II			0	
Modifier III			0	
Modifier IV			0	
Modifier V			–	
Modifier VI			0	
Modifier VII			-3	
Modifier VIII			0	
Modifier IX			0	
Total			78	

TABLE II

W1
Viewing direction (W1 or W2)

1. Average initial FC (E_t)	108.6
2. E_{Vr} (total)	27.2
3. Percent E	25 percent
4. ESI	

Grades

	Actual value	Grade
Visual comfort (VCP or RVC)	78	B
Visual performance (ESI)	44	C

Engineer's signature Milly Amp Architect's signature Beau Drawing

Date January 30, 1975 Date FEBRUARY 2, 1975

Example Computer Printout on a Proposed Lighting System

CUSTOMER :	State of California
PROJECT DESCRIPTION :	Typical Classroom Lighting
LUMINAIRE MANUFACTURER :	Commercially Available 2 x 4 Troffer
LUMINAIRE NUMBER :	ABC 000
PHOTOMETRIC TEST REPORT :	SCZ 1175-1
LAMP ORDERING ABBEVIATION :	F40 CW
LUMENS PER DATE :	3150
LUMINAIRE ORIENTATION :	North - South
LIGHT LOSS FACTOR :	1 Assigned
MOUNTING HEIGHT :	6.5 feet above workplane

Number of Luminaires Installed ______ 20
Average Illumination, Footcandles ______ 88

ROOM DIMENSIONS, REFLECTANCES AND LUMINANCES

North Wall	30.0 feet	Refl.	50 %	Lum = 28.1 Ft. L
East Wall	30.0 feet	Refl.	50 %	Lum = 26.9 Ft. L
South Wall	30.0 feet	Refl.	50 %	Lum = 28.1 Ft. L
West Wall	30.0 feet	Refl.	50 %	Lum = 26.9 Ft. L
Ceiling Cavity	80 % Refl.			Luminance 16.7 Ft. L
Floor Cavity	20 % Refl.			Luminance 17.6 Ft. L

EQUIVALENT SPHERE ILLUMINATION - FOOTCANDLES, INITIAL DISTANCE FROM THE WEST WALL

ESI LOOKING NORTH

	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5
14.50	35.2	53.5	74.2	77.2	63.1	47.7	48.9	67.8	84.7	85.3	69.7	52.2
13.50	47.9	64.9	80.8	83.8	74.7	63.9	65.4	79.0	91.7	92.5	81.0	69.1
12.50	58.1	71.9	83.9	86.9	81.3	74.7	76.0	85.7	95.3	96.1	87.7	79.3
11.50	55.2	68.8	81.1	84.2	78.1	71.2	72.5	82.4	92.3	93.0	84.4	75.9
10.50	44.6	59.4	75.1	78.2	68.8	59.1	60.4	73.1	85.7	86.3	75.0	79.3
9.50	34.1	49.4	69.2	72.3	58.6	45.8	46.8	62.8	79.8	80.4	64.8	49.5
8.50	27.3	43.3	65.8	68.9	51.6	37.7	38.6	55.6	76.2	76.9	57.4	40.8
7.50	27.8	44.7	67.8	70.8	53.4	38.4	39.3	57.5	77.9	78.5	59.4	41.8
6.50	35.1	53.1	73.7	76.7	62.7	47.5	48.6	67.0	83.7	84.4	68.9	51.6
5.50	47.1	63.7	79.3	82.2	73.2	62.7	64.0	77.3	89.2	89.9	79.1	67.3
4.50	56.6	69.8	81.1	83.9	78.7	72.3	73.5	82.5	90.9	91.6	84.2	76.3
3.50	52.7	64.9	75.9	78.4	73.3	67.1	68.2	76.8	84.8	85.4	78.4	70.9

EQUIVALENT SPHERE ILLUMINATION - FOOTCANDLES, INITIAL DISTANCE FROM THE WEST WALL

ESI LOOKING SOUTH

	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5
14.50	27.9	45.0	68.2	71.2	53.9	38.7	39.6	57.9	78.3	78.8	59.6	41.8
13.50	27.2	43.3	65.9	69.0	51.7	37.8	38.6	55.5	76.1	76.6	57.1	48.5
12.50	33.8	49.0	68.9	72.0	58.3	45.4	46.4	62.2	79.1	79.6	63.8	48.7
11.50	43.7	58.4	74.2	77.3	67.9	58.1	59.3	71.9	84.5	84.9	73.5	62.0
10.50	53.5	67.1	79.5	82.6	76.5	69.5	70.8	80.4	89.8	90.4	82.1	73.5
9.50	55.6	69.4	81.5	84.5	79.0	72.1	73.3	82.9	91.1	92.4	84.5	76.1
8.50	45.1	61.6	77.6	80.6	71.3	60.4	61.7	75.4	87.5	88.0	77.0	64.6
7.50	32.6	49.6	70.1	73.2	58.7	44.0	45.0	62.8	79.9	80.3	64.4	47.4
6.50	25.0	40.8	62.5	65.6	48.2	34.5	35.3	51.6	72.2	72.7	53.1	37.1
5.50	23.8	38.5	59.1	62.2	45.3	32.7	33.5	48.5	68.7	69.2	49.7	35.1
4.50	29.1	42.6	60.8	63.8	49.9	38.7	39.5	53.2	70.3	70.8	54.7	41.2
3.50	37.8	49.9	65.1	68.0	58.0	48.7	49.6	61.5	74.4	74.9	62.9	51.6

EQUIVALENT SPHERE ILLUMINATION - FOOTCANDLES, INITIAL DISTANCE FROM THE WEST WALL

ESI LOOKING EAST

	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5
14.50	79.9	83.8	84.7	85.7	89.8	95.0	96.3	93.0	89.9	88.8	91.5	95.3
13.50	73.4	75.4	72.8	70.1	74.3	82.1	85.9	82.9	77.3	72.9	75.7	82.4
12.50	63.8	61.7	53.0	48.0	53.7	66.4	73.9	68.3	57.0	50.2	55.0	66.8
11.50	57.9	54.3	43.7	37.4	42.1	56.6	65.5	59.7	46.7	39.1	43.1	56.0
10.50	57.5	53.9	43.4	37.1	41.9	55.2	65.1	59.2	46.4	38.8	42.8	55.5
9.50	62.6	60.4	51.7	46.8	52.4	65.0	72.4	66.7	55.5	48.9	53.5	65.1
8.50	71.1	73.1	70.3	67.7	71.8	79.5	83.2	80.1	74.4	70.1	72.8	79.4
7.50	76.5	80.3	81.1	82.0	85.9	90.6	91.6	88.3	85.5	84.6	86.8	90.4
6.50	75.2	78.8	79.6	80.5	84.4	88.8	89.8	86.7	83.9	82.9	85.2	88.6
5.50	66.9	68.9	66.0	63.1	67.2	74.8	78.4	75.2	69.5	65.1	67.8	74.6
4.50	55.5	53.0	44.7	40.2	45.0	56.6	63.9	58.0	47.2	41.6	45.5	56.4
3.50	47.5	43.9	34.6	29.0	32.8	43.7	52.2	46.7	36.1	29.8	33.1	43.6

EQIVALENT SPHERE ILLUMINATION-FOOTCANDLES, INITIAL DISTANCE FROM THE WEST WALL

	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5
14.50	79.4	77.3	77.0	80.3	85.2	89.6	90.3	87.7	86.3	87.9	91.8	95.8
13.50	68.2	61.6	60.7	67.9	75.8	80.3	78.2	72.3	70.4	75.6	81.9	85.6
12.50	54.3	43.2	40.5	48.3	61.3	68.6	62.7	51.9	48.2	55.5	67.5	73.8
11.50	45.7	33.8	31.3	39.6	52.9	60.2	52.0	40.6	37.3	45.3	56.6	65.2
10.50	45.4	33.5	31.0	39.3	52.4	59.7	51.5	40.1	36.9	44.8	58.0	64.6
9.50	53.1	42.2	39.5	47.0	59.7	66.9	60.9	50.2	46.6	53.6	65.4	71.8
8.50	66.1	59.3	58.3	65.3	73.2	77.7	75.4	69.5	67.4	72.5	78.8	82.4
7.50	76.5	74.1	73.6	76.7	81.4	85.8	86.3	83.7	82.1	83.7	87.1	90.7
6.50	75.2	72.8	72.2	75.2	79.8	84.4	84.9	82.2	80.5	82.1	85.5	88.9
5.50	62.4	55.4	54.2	60.9	68.6	73.3	71.0	64.8	62.6	67.9	74.2	77.8
4.50	47.5	37.2	34.5	40.8	51.7	59.1	53.0	43.3	39.9	45.9	57.1	63.5
3.50	38.0	27.1	24.5	31.5	42.3	48.3	41.3	31.7	28.7	35.3	46.2	52.1

HORIZONTAL FOOTCANDLES - DISTANCE FROM THE WEST WALL

	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5
						FOOTCANDLES						
14.50	87.8	91.6	94.5	96.9	98.9	100.3	101.2	101.8	102.2	102.7	103.1	103.3
13.50	89.4	93.2	96.1	98.4	100.5	102.1	102.9	103.5	103.8	104.2	104.7	105.1
12.50	91.2	95.0	97.8	100.2	102.4	104.1	104.9	105.3	105.5	106.0	106.6	107.0
11.50	92.4	96.2	98.9	101.3	103.6	105.3	106.2	106.5	106.6	107.1	107.7	108.3
10.50	92.1	95.9	98.6	100.9	103.2	105.0	105.8	106.1	106.2	106.7	107.3	107.9
9.50	90.3	94.0	96.7	99.1	101.2	102.9	103.7	104.1	104.3	104.7	105.3	105.8
8.50	87.9	91.6	94.4	96.7	98.7	100.2	101.1	101.5	101.8	102.3	102.7	103.1
7.50	85.8	89.5	92.3	94.5	96.4	97.8	98.6	99.2	99.5	100.0	100.4	100.6
6.50	85.0	88.7	91.4	93.6	95.5	96.9	97.6	98.2	98.5	98.9	99.3	99.6
5.50	85.5	89.1	91.7	93.9	95.8	97.3	98.0	98.4	98.7	99.1	99.6	99.9
4.50	86.0	89.4	91.8	93.9	95.9	97.5	98.2	98.5	98.6	99.0	99.6	100.1
3.50	85.3	88.5	90.8	92.8	94.8	96.4	97.1	97.2	97.3	97.6	98.2	98.8

THE AVERAGE ILLUMINATION AT THESE POINTS IS 98.7, THE LEFT COLUMN IS DISTANCE FROM THE SOUTH WALL.

THE FOLLOWING ESI RATINGS ARE BASED ON THE ACCEPTED IES RATING SYSTEM FOR THE ABOVE VIEWING DIRECTIONS AND POINT LOCATIONS.

ESI FOOTCANDLES	PERCENT WORK STATIONS	TOLERANCE LEVEL
54	70	99
52	75	99
47	80	99
44	85	99
40	90	99
35	95	99
27	99	99

THE LUMINAIRE CENTERS ARE LOCATED AT:

NORTH - SOUTH DIRECTION	3.00	11.00	19.00	27.00	
EAST - WEST DIRECTION	3.00	9.00	15.00	21.00	27.00

THE NORTH - SOUTH DIRECTION DISTANCES ARE MEASURED FROM THE SOUTH WALL. THE EAST - WEST DIRECTION DISTANCES ARE MEASURED FROM THE WEST WALL.

A list of firms offering computer services required for this procedure is available for review in the offices of the:

California State Department of Education
Bureau of School Facilities Planning

721 Capitol Mall
Sacramento, CA 95814

601 West Fifth Street
Los Angeles, CA 90017

Appendix IX
Glossary of Terms, Abbreviations, and Symbols

Candela (cd). An international unit of luminous intensity.

Candlepower (cp). A measure of the intensity of emitted light in a given direction.

Centimetre (cm). A metric unit of length equal to 0.39″.

Coefficient of utilization. The ratio of the luminous flux (lumens) from a luminaire received on the work plane to the lumens emitted by the luminaire's lamps alone.

Contrast rendition. A measure of the extent to which the contrast between the dark and light portions of a task is maintained by the lighting system.

Contrast rendition factor (CRF). The ratio of the contrast of a task under a given lighting system to that of the same task under uniform hemispherical lighting, measured by means of the visual task photometer.

Es. Illumination on the task with the shield in place.

ESI. Equivalent sphere illuminance. The effectiveness of a lighting system in rendering contrast, expressed as the amount of illumination required from a uniform hemispherical lighting system to produce the same visibility of the task as does the lighting system being investigated.

Et. Average initial illumination level. For measurement it is the illumination without the shield in place.

Evr. Total illumination from the veiling reflection (glare) zone.

Floor cavity. The space between the work plane and the floor.

Footcandle (fc). A measure of the amount of illumination on a surface.

Footlambert (fl). A measure of the luminance (brightness) of a surface.

Interreflected flux. Light that falls on a surface after first being reflected one or more times from surfaces within the room. All light on a surface except that which comes directly from luminaires.

$\bar{L}$. Ell-bar. Weighted average luminance of a luminaire, determined under the EAEG (equal area, equal glare) system.

Lumen. A unit of light.

Luminance. The intensity of light emitted or reflected from a surface in a given direction per unit area of the surface. Commonly called "brightness."

Lux. A unit of illumination equal to the direct illumination on a surface that is everywhere 1 metre from a uniform point source of 1 candle or equal to 1 lumen per m^2.

Metre (m) A metric unit of length equal to 39.37″.

MHwp. Mounting height above the work plane.

Nadir. A point directly opposite zenith, zero degrees vertically.

Percent E. Percent of the total illumination.

Reflectance. The ratio of light reflected from a surface to that falling on the same surface, usually expressed as a percent.

Room cavity. The space between the work plane and the mounting height of the luminaires.

RVC. Relative visual comfort. Where, for the convenience of this procedure, modifications are made to true VCP ratings or other base values, the result is called RVC to distinguish between the value established by accepted procedures and that developed by modification of computed values.

Specular. A type of reflectance in which light rays are reflected in the manner of a mirror, as opposed to a "diffuse" type, in which light is scattered evenly in all directions.

Task luminance. The average or overall luminance of a selected task. For pencil on paper the standard task luminance is computed on the basis of an assumed 70 percent task reflectance.

Transmittance. The ratio of light transmitted through a panel to that falling on it. Usually expressed as a percent.

VCP. Visual comfort probability. A rating that indicates the percent of people who would be comfortable working under a given lighting installation.

Veiling reflections. Reflections from the surface of an object or task that partially obscure the details, thus reducing the contrast.

VTE. Visual task evaluator.

VTP. Visual task photometer.

W1. Wall one (or W2 - Wall Two, and so forth).

ϕ. Correction factor.

77-25 03-0439 300 12-77 4,500